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Mangrove crab (*Scylla serrata*) populations may sometimes be best managed locally

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Abstract

Mangrove crabs (*Scylla serrata*) were trapped in summer and fall 2004 at four sites, each in a separate municipality on the Pacific island of Kosrae, Federated States of Micronesia. Carapace width (CW) of the 219 crabs averaged 15.1 ± 0.13 cm (SE), slightly larger than the mean size of 221 crabs trapped from the same sites 4 y earlier. Mean CW of the 56 crabs in the upper quartile was 17.5 ± 0.17 cm (SE). In the current study, both sizes of crabs as well as degree and direction of change in size from summer to winter varied among the municipalities. The average CW of crabs from one municipality was significantly larger than from any of the other municipalities. Average CW of crabs from another municipality decreased from summer to fall. These results suggest that although the island-wide crab population appears to be stable, some municipalities may wish to enact site-specific management policies to obtain a harvest regimen that will meet local needs.
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1. Introduction

Mangrove crabs (*Scylla* spp., also called mud crabs) are large, tasty, and relatively easy to capture, making them an increasingly scarce resource throughout the Indo-Pacific region (Brown, 1993; Marichamy and Rajapackiam, 2001). In spite of continued harvest pressure, these crabs are managed in only a few parts of their range, most notably in northern Australia (e.g., Pillans et al., 2005). Consequently, they have become smaller and harder to catch in many places, especially in developing countries. Appropriate harvest policies for these large crabs (carapace width, or CW, of males can reach 25–28 cm: Carpenter and Niem, 1998, reported by Williams and Primavera, 2001) might sustain a source of protein and cash for many communities. The purpose of this study was to analyse local differences in crab populations both spatially and temporally in order to suggest simple but meaningful management practices.

Although four species of mangrove crab are now recognised (Keenan et al., 1998), only one species (*Scylla serrata*, the most widespread) is found on the island of Kosrae, Federated States of Micronesia, where it is one of the most valuable products harvested from the island's mangrove forests (Naylor and Drew, 1998). On Kosrae, mangrove crabs are prized for family feasts, sold to local tourist hotels, and exported primarily as gifts to

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family members in Guam, Hawaii, and elsewhere in the Pacific islands. The crabs may be either trapped in small estuaries and tidal creeks or collected by hand in mangrove forests. Household surveys suggest that catch per unit effort (CPUE) declined from 1990 to 2000, the number of households participating in crab harvesting also decreased, and fewer harvesting trips were made each month (Naylor et al., 2002). Nevertheless, the number of crabs exported from Kosrae for sale and for gifts increased from 1997 to 2000.

A sample of 368 crabs caught from 1999–2001 primarily by traps set along interior and fringe mangrove channels and by hand along randomly selected transects in Kosrae averaged 15.2±2.4 cm (SD) in CW (Bonine et al., 2008); the largest was 21.0 cm. In April 2000, in response to the growing sense documented above that crabs were getting smaller and harder to catch, a new law passed by the Kosrae State Legislature established a minimum harvestable size limit of 6 in (15.2 cm) “measured along the largest diameter across the outside of the shell” (Kosrae State Legislature, 2006). The law also prohibited export of mangrove crabs and declared a closed season from 1 August through 31 December. This law was unpopular, and the portions prohibiting export and declaring a closed season were repealed the following year. During the time the law was in effect, people may have continued to harvest crabs for family consumption, but none were sold to hotels on the island or exported during the 5-mo ban.

The objectives of this study were to determine how the mean CW of crabs and CPUE in Kosrae might have changed since the earlier study, as well as how variable they might be both around the island and over shorter periods of time. I also wanted to determine whether different locations on the island might benefit from different regulations.

2. Materials and methods

2.1. Study sites

Kosrae (5°19′N, 163°E) is a high volcanic island in the eastern Caroline Islands in the Pacific Ocean and is one of four island-states in the Federated States of Micronesia. It is ~104 km^2 in area with a narrow coastal plain and a mountainous interior. With rainfall of ~4–5 m y^{-1} and no distinct dry season, several small rivers traverse the coastal plain and flow through mangrove forests that vary from narrow strips to belts as wide as 800 m.

Most of Kosrae’s ~ 7800 people live on the coastal plain. The island is divided into four municipalities: Lelu, Malem, Utwe, and Tafunsak (Fig. 1), each with at least one village as a population centre. In spite of Kosrae’s small size, these municipalities differ socioeconomically (Table 1).

Lelu contains the government offices for the State of Kosrae. It has a number of wealthy and influential families, an active harbour, and many small businesses, and in most households at least one member has a salary. The Pukusrik Tidal Channel, the trapping location for Lelu, is lined by narrow strips of mangrove forest and terminates in a large stand of mangroves. Many Lelu households are located along the landward edge of the mangroves; many of these residents own boats, and they harvest crabs and fish.

At the other socioeconomic extreme, the municipality of Utwe contains many subsistence-level households, especially in the underpopulated southwestern part of the island. Trapping was conducted in the Utwe-Walung Tidal Channel, which provides boat access during high tide to some of the most remote, extensive, uninterrupted mangrove forests on the island. In Utwe, several women earn money by catching crabs by hand. Crabs were exported commercially from Utwe before 2000, but those were harvested on the other side of the municipality, distant from the Utwe-Walung Tidal Channel and closer to the remote village of Walung (which is part of Tafunsak municipality).

Malem, with a moderate income level, is located on a high-energy coastline where boat access is difficult. Few people in Malem have fishing boats, and the only place where they can harvest crabs is along the Inya River, which is actually part of Utwe.

The fourth municipality, Tafunsak, is the location of another major harbour and the airport, so it has several small businesses and a moderately high standard of living. The trapping location for Tafunsak was the Okat River, which is beyond the harbour and the main concentration of households. Most of the mangroves in this municipality are found in a belt several hundred metres wide and stretching from north of the Okat River south to Walung. Before 2000, crabs were harvested from the Okat River for commercial export to other Micronesian islands, especially Guam, but this enterprise did not resume after the law was repealed.

Little is known about the life history of the mangrove crabs from spawning through the larval stages. However, once the crabs have matured enough to migrate from the reef into a mangrove forest, their long-shore movements are known to be limited (Hill, 1975; Perrine, 1978; Hyland et al., 1984; Bonine et al., 2008). The area of mangrove forest within 0.5 km around each channel where traps were set was measured on a vegetation map

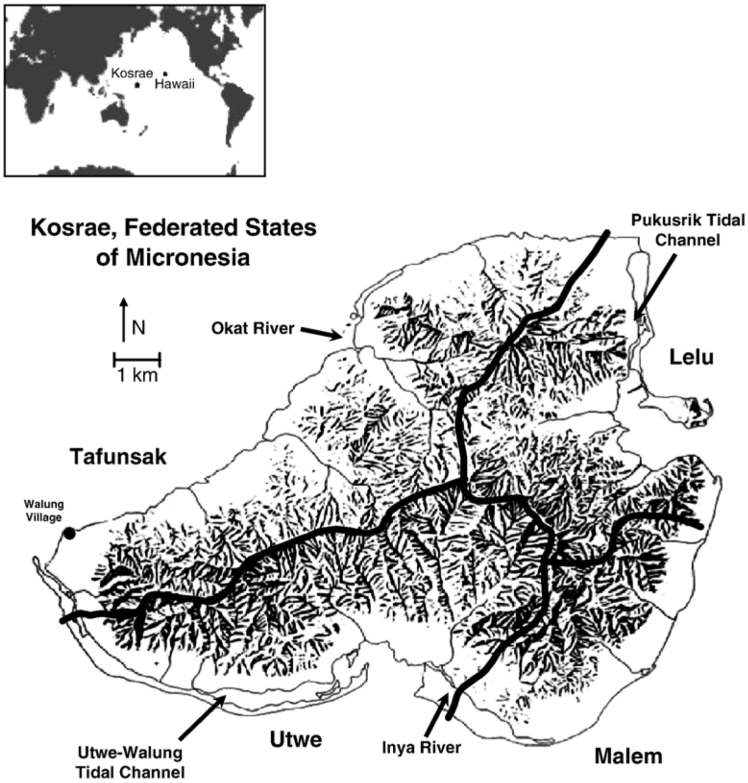

Fig. 1. Location of municipalities and study sites in Kosrae, Federated States of Micronesia.

(Whitesell et al., 1986) (Table 1). Except for extent of mangroves and degree of harvesting, primarily for firewood (Table 1), there are no known differences among the mangrove forests surrounding the sites where traps were set for this study.

2.2. Trapping protocol

I sampled crabs on a more systematic basis than in the earlier study, trapping at four sites before and after an interval ranging from 4.5 to 5.5 mo. Recruitment for mangrove crabs appears to be aseasonal in many tropical environments (Brown, 1993), and Kosrae's climate has little seasonality (Krauss et al., 2006), indicating that the actual time of year when trapping occurs is not likely to be important. Because mean size of a population sample may be biased by entry of a new cohort of crabs, the mean size of the largest quartile from each sample was also calculated. Decreases in the largest quartile could reflect over-harvesting, because individuals do not have an opportunity to grow into larger size classes.

Crabs were sampled from the four sites in mid-June to mid-July 2004 (summer) and again from mid-

Table 1
Characteristics of municipalities (FSM Dept. Econ. Affairs, 2000) and sites where crabs were sampled

Municipality	Population density (persons km^{-2})	Median household income (US$)	Percent of adults living at subsistence level	Sampling site	Extent of mangroves around channel (ha)	Percent area harvested annually between 1996–2000 (Hauff et al., 2006)
Lelu	124	$9155	2.9	Pukusrik Tidal Channel	49	1.7
Malem	93	$7156	11.8	Inya River	61	1.1
Tafunsak	58	$7626	10.6	Okat River	61	1.9
Utwe	37	$5833	12.6	Utwe-Walung Tidal Channel	185	1.2

Table 2
Trapping schedule in 2004 and numbers of mangrove crabs trapped

Municipality	Site sampled	Summer dates of trapping	Number of crabs trapped	Summer CPUE	Fall dates of trapping	Number of crabs trapped	Fall CPUE
Lelu	Pukusrik Tidal Channel	15 – 19 June	29	0.73	30 November – 4 December	30	0.75
Malem	Inya River	6 – 10 July	43	1.08	23 – 27 November	25	0.63
Tafunsak	Okat River	22 – 26 June	34	0.85	7 – 11 December	22	0.55
Utwe	Utwe-Walung Tidal Channel	29 June – 3 July	20	0.50	16 – 20 November	16	0,40
OVERALL			126	0.79		93	0.58

November to mid-December (fall) (Table 2). Eight crab traps ~ 1.2×0.6×0.3 m were constructed of 2.5-cm mesh wire. They were baited with fish, set out for five consecutive nights (40 trap nights) at a single site, and checked daily. The sites were trapped in this manner, one after the other, over four consecutive weeks in each season.

2.3. Data analysis

Differences in CW described below were tested using SAS/STAT® software, Version 9.1 of the SAS System for Windows (SAS Institute Inc., 2000–2004). Student's t-test was used to determine significance ($p<0.05$) of the seasonal difference between mean CW and between mean CW of the upper quartile of the crabs. The sample sizes of the two populations were pooled to determine the degrees of freedom for the t-test when the folded F statistic (Steele and Torrie, 1980) indicated that the variances of the two populations were equal. The Satterthwaite method (Satterthwaite, 1946) was used to determine the degrees of freedom for the t-test when the folded F statistic indicated the two populations had unequal variances. The t values calculated using these two methods are designated as t_{pooled} and t_{Sat}, respectively. Differences between CWs for municipalities within seasons were tested for homogeneity of variance using Levene's test. The data were natural-log-transformed when Levene's test indicated the variances were unequal. Tukey's Studentized Range Test at the 5% significance level was used to determine differences among municipalities for transformed and untransformed means. Means of the upper quartile were calculated and compared in the same manner. A paired Student's t-test in Excel was used to determine whether a significant difference ($p<0.05$) existed in CPUE at all sites between the two seasons.

3. Results

CW of the 219 crabs that were trapped in summer and fall in the four municipalities averaged 15.1 cm (Table 3). Mean CW of the crabs trapped in fall was not significantly ($t_{Sat.}=1.61$, df=156, $p=0.109$) larger than for those trapped in summer, but the mean CW in the upper quartile was significantly larger in fall than in summer ($t_{pooled}=3.42$, df=54, $p=0.001$).

In summer 2004, mean CW of crabs from Utwe was significantly ($F=13.4$; df=3,122; $p<0.0001$) larger than for crabs from the other municipalities. By fall 2004, Utwe crabs were still significantly wider, but Malem crabs were then significantly smaller than in the other municipalities ($F=28.6$; df=3,89; $p<0.0001$). Mean width of crab carapaces in the upper quartile was significantly larger in Utwe than in the other municipalities in

Table 3
Average CWs of all crabs trapped in 2004 in this study and of crabs in upper quartile

	All crabs			Upper quartile		
Island-wide	Overall	Summer	Fall	Overall	Summer	Fall
Mean (cm)	15.1	14.9	15.4	17.5	17.0a	18.1b
SE (cm)	0.13	0.15	0.24	0.17	0.20	0.27
N	219	126	93	56	32	24
Utwe						
Mean (cm)	17.6	16.9	18.5	19.6	19.3	20.1
SE (cm)	0.33	0.46	0.39	0.44	0.24	0.97
N	36	20	16	9	5	4
Lelu						
Mean (cm)	15.0	14.3a	15.5b	16.5	16.0a	17.1b
SE (cm)	0.20	0.25	0.27	0.18	0.17	0.13
N	59	29	30	16	8	8
Tafunsak						
Mean (cm)	14.8	14.6	15.0	16.3	16.1a	16.7b
SE (cm)	0.18	0.22	0.32	0.13	0.11	0.22
N	56	34	22	15	9	6
Malem						
Mean (cm)	14.2	14.6b	13.5a	15.9	15.8	16.0
SE (cm)	0.20	0.17	0.42	0.11	0.15	0.19
N	68	43	25	18	11	7

Different lower case letters indicate a significant difference ($p<0.05$) between seasons.

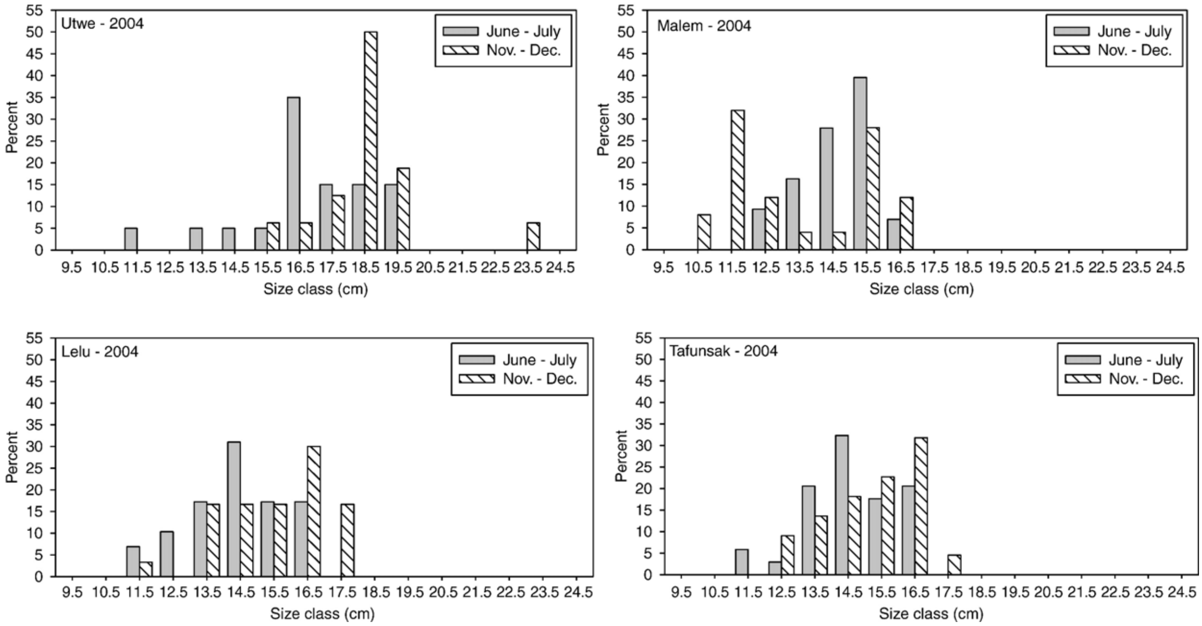

Fig. 2. Age-class distributions of mangrove crabs trapped in summer and fall 2004 in four municipalities in Kosrae, Federated States of Micronesia.

both summer and fall (summer: $F=64.9$; $df=3,29$; $p<0.0001$; fall: $F=20.9$; $df=3,21$; $p<0.0001$).

Mean CW was significantly larger in fall than in summer for Lelu ($t_{pooled}=3.22$, $df=57$, $p=0.002$), Malem ($t_{Sat.}=2.54$, $df=31.8$, $p=0.016$), and Utwe ($t_{pooled}=2.49$, $df=34$, $p=0.018$), but there was no significant seasonal difference for crabs in Tafunsak ($t_{pooled}=1.18$, $df=54$, $p=0.242$). Mean CW of the upper quartile was significantly larger in fall than in summer in Lelu ($t_{pooled}=5.32$, $df=14$, $p=0.0001$) and Tafunsak ($t_{pooled}=2.29$, $df=13$, $p=0.039$), but there was no significant seasonal difference in either Malem ($t_{pooled}=0.81$, $df=16$, $p=0.430$) or Utwe ($t_{Sat.}=0.84$, $df=3.38$, $p=0.456$).

Size-class histograms suggest that a crab in Kosrae is not captured in a trap until its CW reaches ~ 10.5 cm (Fig. 2). The largest crab trapped in this study was from Utwe and had a CW of 23.0 cm. In Malem, the smallest size classes were trapped only in fall, and no larger size classes were present in fall than in summer. In the other three sites, the largest size class was in the fall.

CW of 221 crabs that were trapped from the same sites in the earlier study as in this study averaged 14.7 ± 0.14 (SE), and the mean of the upper quartile was 17.1 ± 0.13 (SE).

CPUE did not differ significantly from summer to fall among the four sites ($t=0.898$, $df=3$, $p=0.14$). The overall CPUE, including data from both seasons and all municipalities, was 0.685 crab per trap night.

4. Discussion

Significant differences among populations of *Scylla serrata* at four sites around Kosrae and across a time span of 4 mo demonstrate the importance of local environmental conditions and management practices to this species. Crabs from the Utwe-Walung Tidal Channel in the municipality of Utwe included the largest individuals of all four municipalities, and neither overall mean size nor mean size of the upper quartile changed from summer to fall (Fig. 2). Human population density is lowest on this part of the island, mangroves are the most extensive among the four sites, and subsistence life styles are most common, so more trips are made to collect crabs, and more crabs are collected (Tables 1 and 2; Naylor and Drew, 1998; Naylor et al., 2002). Perhaps the large, remote mangrove forest beyond the area trapped acts as a reserve, so that crabs have more opportunity to grow to large sizes than on other parts of the island. With the recent construction of a new road to the remote village of Walung, access to these mangrove forests and ease of getting to a market may increase pressure on this population.

Harvest pressure on mangrove crabs has traditionally been lowest in the municipality of Malem (Naylor et al., 2002). Nevertheless, CW of the Inya River population, both overall and in the upper quartile, decreased during this study (Table 3, Fig. 2), suggesting that the population at this site cannot support even a relatively modest harvest level. Mean CW in the upper quartile increased in both the Pukusrik Tidal Channel (Lelu) and the Okat River (Tafunsak), and overall mean CW of Pukusrik crabs also increased (Table 3, Fig. 2). The Resource Management Committee in Lelu considered several management options during this project and is now establishing a marine protected area in part of Lelu Harbour, which is adjacent to Pukusrik (although the mangrove forests are not contiguous). The crab population in Tafunsak's Okat River may still be recovering from extensive trapping for commercial use before 2000.

The presence of significant differences in CW among mangrove crabs on different parts of the island reinforces earlier observations in Kosrae (Bonine et al., 2008) and is consistent with other studies describing restricted movement from one mangrove stand to another elsewhere in Micronesia (Pohnpei, Federated States of Micronesia: Perrine, 1978) and in the Indo-Pacific, including Australia (Hyland et al., 1984; Pillans et al., 2005) and for *S. paramamosain* in Vietnam: Le Vay et al., 2007). Because of a high degree of site fidelity and likely differences in harvest pressures arising from socio-economic differences, site-specific harvest regulations could be an effective way of managing mangrove crab populations to meet local needs in many places.

However, the degree of genetic isolation of each population is still not understood for any of the species of mangrove crabs, because of the difficulty of tracking larval stages before they settle in mud flats and mangrove forests as juveniles. Understanding the nature of dispersal of mangrove crabs during their larval stages is still important to understanding the long-term implications of management or mismanagement of adjacent populations along a shoreline.

Trends in CW and CPUE from 1999 to 2004 suggest that the overall population on Kosrae may be stable. Harvest pressure may have decreased since the earlier study (Bonine et al., 2008), perhaps because of heightened awareness of the species' vulnerability. The existing regulation that no crab of CW <6 in (15.2 cm) may be taken appears to be protecting the overall population adequately.

Further study to examine such environmental characteristics as spatial variation in food sources for crabs and effects of waste disposal in mangrove forests may help achieve a better understanding of differences in size characteristics among different sites on Kosrae, justifying additional restrictions such as prohibiting the harvest of females, establishing marine protected areas, or suspending harvest occasionally for a few months where appropriate. Regular monitoring of the crab populations at the same sites, perhaps at yearly intervals, should enable island resource managers to determine if additional regulation is needed.

This study demonstrated that populations of *S. serrata* can develop distinctive size distributions because of differing environmental conditions and harvest patterns. Even size at maturity for a related species can vary from one population to another (*S. paramamosain*: Walton et al., 2006). The existence of site fidelity and local variations in growth patterns not only in *S. serrata* but in other species of mangrove crabs as well suggests that local regulations in addition to regional restrictions may be appropriate for many sites in the Indo-Pacific. Monitoring populations on a regular basis may increase the ability of small, remote communities to manage an important resource sustainably.

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